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A Review of Intraosseous Vascular Access: Current Status and Military Application

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Austere far-forward battlefield environments present numerous obstacles in providing adequate medical care to the injured soldier. In addition to logistical constraints that limit the volume of isotonic crystalloid fluids available to resuscitate the injured soldier, hypotension, environmental and tactical conditions, and/or the presence of mass casualties can combine to lead to excessive delays in obtaining vascular access. For many years, intraosseous infusion has been a rapid, reliable method of achieving vascular access under emergency conditions in children. Although intraosseous infusion in adults was used extensively in the 1930s and 1940s, and a sternal puncture kit for bone marrow infusions was a common component of emergency medical supplies during World War II, only recently have there been discussions and experimental studies to evaluate intraosseous infusions in adult medical emergencies. With some medical elements of the U.S. military having recently been reissued intraosseous devices, we thought it timely to review the literature on this technique. This review discusses the efficacy and safety of intraosseous infusions of drugs and fluids, including insertion times and flow rates achieved. Although the intent is to evaluate the feasibility of the technique in the injured soldier, literature citations from studies in children, experimental animals, and human cadavers are included to support the statements made and to offer the reader the opportunity to read the original literature.

Introduction

Acute hemorrhage is the major cause of battlefield deaths in conventional warfare, accounting for 50% of fatalities.[1] In addition, in about 30% of injured soldiers who die from wounds, hemorrhage is the primary cause of death. Many improvements in prehospital combat casualty care will be necessary before these traditionally high death rates can be decreased. Although methods of improved hemorrhage control and the type and amount (cube and weight) of resuscitation fluids have been debated, the actual routes of fluid, drug, and blood administration in the prehospital environment have been critically examined only recently. The most viable routes appear to be traditional venous cannulation with plastic catheters or intraosseous access. However, the injured soldier's hypotensive state and collapsed peripheral veins, combined with environmental and tactical conditions and/or the presence of mass casualties, are significant factors that may impede obtaining vascular access in a timely manner.

Although a recent study at an urban trauma center suggested that prehospital fluid administration in hypotensive patients with penetrating trauma offered no survival advantage compared with patients who received little or no preoperative fluid,[2] it appears that some amount of resuscitation is required to prolong survival when the preoperative phase is longer than 90 to 120 minutes.[3,4] This end point of resuscitation is not well defined, but there is general agreement that some resuscitation will be required to sustain soldiers with delayed access to definitive hemorrhage control. In World War II, this end point was clearly defined in 2,853 battle casualties as a systolic pressure of 80 to 85 mm Hg, as long as the patient's color was good and the skin was warm.[5]

Despite widespread use of venous catheters, it is recognized that potential major limitations of prehospital resuscitation relate to time delays and failure rates associated with obtaining vascular access.[6] In civilian emergencies, these problems have been associated with collapsed veins, clotting at the injection site, and the presence of obesity. For example, in cases of cardiac arrest or shock in 66 pediatric patients, intravenous access could not be obtained in 6% and required a minimum of 10 minutes in an additional 24%.[7] Under combat conditions, it is conceivable that these other problems, with the exception of obesity, will be magnified by the difficulty of care while under fire. Furthermore, placement of venous catheters in hypotensive patients can be difficult, especially if the provider lacks regular experience in dealing with such patients. Therefore, investigations have begun to address improved methods for obtaining vascular access more rapidly and reliably, particularly in far-forward, austere battlefield settings.

During the past two decades, an extensive body of literature has accumulated regarding the use of the intraosseous (IO) route as an emergency alternative to gain intravenous access. Most of the reports involved pediatric patients, in whom the technique was considered the most useful and versatile alternative.[7,8] (A technique for insertion of an IO needle into the proximal tibia of children is described.[8]) Historically, a sternal puncture kit for bone marrow infusions in adults was included in emergency medical supplies during World War II and was used to some extent.[9-13] Several accounts of recent IO use in the adult trauma patient have also been published. These devices are approved by the Food and Drug Administration and are becoming readily available in trauma rooms and prehospital environments, and medical elements of the U.S. military have recently been reissued intraosseous devices. In addition, a recent study with cadavers at the Walter Reed Army Institute of Research reported that Army Special Forces medics, Navy corpsmen, and Air Force pararescue personnel found currently available intraosseous devices and needles easy to use (MAJ M. Calkins, unpublished observations). Because these devices are becoming more popular, we decided to review the available literature on their use. This paper will present a general overview of IO infusion, including history, known complications, types of

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fluids and drugs used and their rates of infusion, and the potential for intraosseous infusion in military operations. Many of the recent clinical studies have involved children, whereas others used experimental animals and cadavers. Nevertheless, these studies were considered essential for this review to validate the technique for use in adult emergencies and to provide essential information for potential users regarding practical insertion times, ease of use, and infusion rates for various fluids and drugs.

Background

It was recognized in the early 1920s that the bone marrow could represent a noncollapsible "vein," thereby providing a means for obtaining rapid vascular access.[14] IO infusion techniques were widely used in emergency situations during the 1940s and 1950s, when blood, fluids, and drugs infused into the red marrow of the sternum or tibia were shown to rapidly and reliably enter the circulation.[15-22] For example, Tocantins[15] showed that Congo red dye injected into the rabbit tibia took approximately 10 seconds to reach the central circulation. In fact, a review of the literature in 1990 indicated that any substance infused intravenously could be injected into bone marrow and that substances injected into the bone marrow were almost immediately absorbed into the general circulation.[23]

The use of IO infusion, however, began to wane with the rapid development of plastic catheters and routine venous cannulation in the 1950s and 1960s, which generally could be left in place longer than IO needles. A renewed interest in IO infusion developed in the late 1970s as IO infusion into the tibia became an accepted practice for emergency vascular access in infants and children,[8,24-28] although other sites were used successfully as well.[29]

Infusion Sites

The red marrow of the long bones becomes slowly replaced by yellow marrow after age 5 years. It is perceived that successful IO infusion requires red marrow, accounting in part for Fiser's[23] recommendation of the tibia for children and the sternum for adults as ideal sites for IO infusions. However, yellow marrow contains numerous venous sinusoids that can support modest IO infusion rates under standard infusion pressures.[13] Recent studies with human cadavers indicate that vascular access was achieved by injection into the yellow marrow,[30] and others have reported acceptable success rates for IO infusions in adult patients.[27,31]

In adults, the sternum, ankle (medial malleolus), and bones of the pelvic girdle remain sites of red marrow and have been reexamined as sites for IO infusions.[31,32] The clavicle also has been used successfully as an IO infusion site in adults.[33,34] The sternum is attractive as an IO infusion site for adults because it is a soft bone, has wide marrow space of relatively uniform geometry, and lies under only a thin layer of skin.[32] The potential danger of using the sternum is that it overlies major vascular structures, and early studies reported that sternal infusions should not be attempted in children younger than 3 years of age.[26,35] Current sternal IO access devices are being developed with a high margin of safety so that bone puncture through to the underlying blood vessels or heart in adults is not likely.[32]

The tibia has an advantage for IO access in that it has a large marrow space, but the outer cortical bone is very hard and manual IO devices cannot be placed easily in the adult tibia. However, tibial injection has been achieved successfully in adults,[31,36] most recently with an automatic device.[36] This device, known as a bone injection gun, incorporates a loaded spring to inject the needle into the tibia, as illustrated and described,[36] although the authors state that use at other sites is possible. In addition, devices specifically designed for infusion into the adult sternum have also been developed. Table I summarizes the various intraosseous infusion sites explored experimentally in animals or clinically. Some sites have been used on numerous occasions, whereas the use of other sites reflects anecdotal reports. Together, these studies support the likelihood of at least two viable intraosseous infusion sites for adult emergencies.

Intraosseous Infusions

Over the years, various drugs, fluids, and blood have been infused successfully into intraosseous sites in children and adults as well as in experimental animals. Numerous studies have reported that effective anesthesia (local and general) in both children and adults can be achieved through the IO route.[36,46-48] In addition, IO sites were effective for emergency resuscitation in children[26,49,50] and for fluid resuscitation from hemorrhagic shock in experimental animals.[43,51-53] Representative drugs and fluids infused through an IO route are listed in Table II. Some of the more common emergency drugs and fluids, such as lactated Ringer's solution and blood, have been infused

TABLE I

INTRAOSSEOUS INFUSION SITES

Site	Species
Tibia	Human (adults[36] and children[28]), pig,[37] cat,[19] rat,[19] dog,[38] cow,[39] sheep,[40] horse,[54] goat,[42] rabbit[43]
Ankle (medial malleolus)	Human (adults),[36] pig[37]
Sternum	Human (adults),[15] pig,[49] sheep[45]
Iliac crest	Human (adults)[20]
Clavicle	Human (adults)[33]
Femur	Human (children),[28] pig,[37] rat[19]
Humerus	Human (children),[17] pig[37]
Calcaneus (heel)	Human (children)[29]

Superscripts denote representative references.

TABLE II

DRUGS AND FLUIDS INFUSED BY IO MEANS IN HUMANS AND EXPERIMENTAL ANIMALS

Anesthetics	Cardiac Drugs and Vasoactives Agents	Fluids	Anticonvulsants and Analgesics[a]	Neuromuscular Blockers	Antimicrobial Agents	Other
Propofol[54]	Epinephrine[49]	Blood[22]	Phenobarbital[55]	Pancuronium[46]	Amikacin[56]	Diazepam[57]
Bupivacaine[58]	Dopamine[50]	Normal saline[59]	Phenytoin[61]	Vecuronium bromide[62]	Clindamycin[63]	Heparin[64]
		Plasma[60]				
Lidocaine[49]	Dobutamine[50]	Lactated Ringer's solution[7]		Succinylcholine[48]	Penicillins[31]	Contrast media[33]
Sodium pentothal[20]	Isoproteenol[65]	Hypertonic saline[64]		Atracurium[66]	Chlortetracycline[20]	Sodium bicarbonate[49]
Ketamine[67]	Atropine[49]	7.5% NaCl/6% dextran (HSD)[53]	Morphine[68]	Suxamethonium[68]	Sulfadiazine[20]	Calcium chloride[69]
	Adenosine[41]	Dextran[20]	Fentanyl[67]			Antitoxins[64]
		4.5% human albumin[7]				
	Digoxin[20]	Hypertonic glucose[22]				Methylene blue[70]
	Ephedrin[39]	Hydroxyethy/starch[69]				Methylprednisone[71]
		Dextrose[49]				Vitamins[20]
		Isosal[72]				

Superscripts denote representative references. This table is not all-inclusive. The reader is referred to the cited studies for other drugs and experimental agents infused through the intraosseous route.
[a]Phenobarbital and phenytoin are anticonvulsants; morphine and fentanyl are analgesics.

into marrow by multiple emergency medical personnel or investigators in humans. Investigational drugs and contrast media and dyes have generally been infused in experimental animals, although a few have been investigated in both animals and humans. In general, IO infusions have been applied in treating the entire spectrum of adult trauma scenarios, such as dehydration, hemorrhage and traumatic injury, cardiovascular collapse, and burns,[18,23,60,73,74] i.e., injuries and conditions similar to those that may be encountered in military casualties.

It was recognized that the tortuous vascular architecture of bone marrow presents substantial hydraulic resistance to infusions. Watson et al.[40] reported that this hydraulic resistance accounted for about 90% of the total resistance and that there was little contribution of resistance from the IO needle itself. It has been shown that drugs, blood, and fluids can be delivered at acceptable flow rates of 20 to 25 ml/min via pressure bags at 300 mm Hg or other high-pressure infusion pumps.[30,32,39,40] As a consequence, a number of studies have reported essentially identical plasma concentrations or onset of physiologic effects of drugs and fluids when IO infusions were compared with both central or peripheral intravenous (IV) infusions in experimental animals.[37,38,41,51,56,69,75-77] Table III summarizes typical flow rates achieved under various experimental conditions and how they compare with standard IV infusion rates. For example, in a swine model of cardiac arrest, Spivey et al.[38] reported that sodium bicarbonate infusion via an IO route was equivalent to, if not better than, peripheral intravenous infusion to increase blood pH. Warren et al.[75] compared infusion rates of normal saline through different IO infusion sites and at different infusion pressures in both normovolemic and hypovolemic piglets. They concluded that although there were statistically significant differences in flow rates among sites, they did not believe them to be clinically significant, suggesting that infusions via the various IO sites were similar to IV infusions. In addition, preliminary studies with adults and human cadavers have reported success rates of insertion and infusion of 80 to 100%, and times to successful infusion typically were 1 minute or less.[20,36,79,83] Table IV summarizes the reported success rates and times to IO insertion in human patients and cadavers. As shown, the majority of insertions were completed within 2 minutes in all studies.

Based on attempts at rapid IO infusion of large volumes of isotonic crystalloid solutions for resuscitation from hemorrhagic shock in animal models, it was concluded that such IO infusions may be useful to resuscitate small children but would be impractical in adults.[26,30,43,51,52,81] Thus, some investigators concluded that under such circumstances, IO infusion would be acceptable initial therapy for adults but that IV infusion should be started as soon as possible if the intent is to infuse large volumes of fluid.[51] This presumed limitation of IO infusion in adults has spawned recent studies to investigate IO resuscitation from hemorrhagic hypovolemia with hypertonic saline/dextran solution (7.5% NaCl/6% dextran-70 [HSD]).[45,53] Because HSD is infused as a small-volume resuscitation (at about one-tenth the shed blood volume), it could be infused via the IO route in adults in a timely manner. Perron et al.[80] showed that a 250-ml dose of HSD (the proposed adult clinical dose) could be administered through the marrow within 4 minutes via a sternal access device that automatically adjusts for variations in tissue and bone thickness to prevent the danger of puncturing underlying tissues.[45,83] Using this sternal access device, Dubick et al.[44] evaluated hemodynamic variables and electrolyte concentrations, as well as evidence for histologic abnormalities in lung and sternum, in euvolemic swine infused with a 4 ml/kg bolus of HSD via either the sternal IO or IV route. They observed virtually identical responses in hemodynamic variables, plasma volume expansion, changes in plasma protein concentrations and hematocrit, and plasma electrolytes when evaluated during the initial 120 minutes after infusion. Similarly, rapid restoration of hemodynamic variables was reported in hemorrhaged, conscious sheep after HSD infusion into the sternum or through a central venous catheter.[45] Other studies have reported the

TABLE III

SUMMARY OF INTRAOSSEOUS FLOW RATES OF DIFFERENT FLUIDS FROM PUBLISHED STUDIES

Investigators	IO Site	Infusion Device	Species	n	Flow Rates	Comments
Iserson[31]	Malleolus	13-ga Jamshidi needle	Human adults	22	5–12 ml/min	Flow under 300 mm Hg pressure for 20–80 min
Iserson and Criss[78]	Malleolus	13-ga Jamshidi needle	Human child (9 kg)	1	200 ml/h	Maximum rate for 5% dextrose
Waisman and Waisman[36]	Tibia and malleolus	Automatic bone injection device	Human adults	50	5–10, 15–20,* 30–40* ml/min 60–100 ml/min	Crystalloid under gravity flow and under *300 mm Hg pressure Manual pressure to syringe
Iwama et al.[33]	Clavicle Ilium Tibia	18-ga Cook IO needle	Human adults	29 21 15	11.9 ± 0.7 ml/kg/h 32.2 ± 4.58 18.9 ± 1.3	Flow by site under gravity and 59 mm Hg; compares with subclavian vein flow of 15.2 ± 1.5 ml/kg/h.
Hurren and Dunn[60]	Tibia	Spinal needle	Human child (13 kg)	1	50 ml/hr	Total of 776 ml of fluids infused over 48 h
Guerrero et al.[79]	Sternum	Sternal access device, 15-ga shaft	Adult cadavers	68	50–100 ml/min	Required 465–1000 mm Hg pressure
Watson et al.[40]	Tibia Sternum	15-, 16-, or 18-ga needle	Adult cadavers, pigs, sheep	20 10 6	Up to 180 ml/min	For LR, required 2,000–2,500 mm Hg pressure
Perron et al.[80]	Sternum	Sternal access device, 15-ga shaft	Sheep	6	50 ml/min 50 ml/min	Flow for normal saline under 525 ± 240 mm Hg pressure
Neufeld et al.[52]	Tibia	18-ga spinal needle	Piglets	12	50 ml/min	Flow for normal saline with manual pressure of 450–475 mm Hg over 20 minutes
Schoffstall et al.[81]	Tibia	18-ga spinal needle 13-ga marrow needle	Pigs (5.8 kg) Pigs (14.4 kg)	8 8	5.8, 19.2* ml/min 3.7, 14.5* 17.4, 51.9* 13.6, 45.9*	Flow for saline or blood under gravity or *300 mm Hg pressure
Warren et al.[75]	Humerus Femur Tibia Malleolus	13-ga bone marrow needle	Pigs (12–23 kg)	23	11.1, 41.3* ml/min 9.3, 29.5* 4.3, 17.0* 8.2, 24.1*	Flows by site under gravity or *300 mm Hg; compares with peripheral IV flows of 13.1 or 40.9* ml/min
Shoor et al.[39]	Tibia	13-ga needle	Calves	6	10 ± 2 ml/min 27 ± 2 32 ± 1 41 ± 2	Gravity + 60 mm Hg for normal saline 100 mm Hg 200 mm Hg 300 mm Hg
Hodge et al.[51]	Tibia	20-ga spinal needle 13-ga bone marrow needle	Dogs (4–6 kg)	4	11, 24* ml/min 13, 29*	Flow for LR, gravity or *300 mm Hg
Gunal et al.[82]	Tibia	20-ga spinal needle with stylet	Dogs (13–17 kg)	7	8 ml/min	Normal saline

ga, gauge; LR, lactated Ringer's solution.

effectiveness of IO infusion of HSD in resuscitating animals from hemorrhagic hypotension.[85-87] Consistent with previous studies, these studies found that delivery of an effective dose of normal saline was limited by the large volumes required and the high hydraulic resistance in the marrow. To date, only one study has investigated IO infusion of HSD in humans. Chavez-Negrete et al.[88] infused HSD by IO and IV routes to patients with gastrointestinal bleeding. They found that HSD reduced the total fluid and blood requirements in these patients compared with standard-of-care infusions and that sternal IO infusion of HSD was as effective as an IV infusion, with no deleterious effects observed.

In addition to delivery of drugs and fluids, the IO site has been used for sampling to analyze blood chemistries, partial pressure of arterial carbon dioxide, pH, and hemoglobin, for typing and cross-matching of blood, and to detect latent malaria or other tropical diseases.[7,13,23,89] However, Ros et al.[59] suggested caution in the microscopic evaluation of blood smears taken from IO lines, at least within the first 30 minutes after IO infusion, because they observed changes in differential white blood cell counts and red cell morphology.

In all, these studies support the feasibility of IO infusion of fluids and drugs in adult emergencies. The major limitation appears to be in attempting to infuse large volumes of isotonic fluids in a timely manner. However, historic data, human studies, and a growing body of animal data suggest that limiting the amount of fluid infused may be more beneficial until hemorrhage control is achieved.[2]

TABLE IV

TYPICAL INSERTION TIMES FOR ACHIEVING INTRAOSSEOUS ACCESS

Investigators	Device	Patients	*n*	Insertion Time	Comments
Guerrero et al.[79]	Sternal access device	Adult cadavers	68	12.5 ± 5.7 seconds	
Schafer et al.[30]	15-ga Jamshidi needle	Adults cadavers	25	Range; 4–30 seconds	
Iserson[31]	13-ga Jamshidi needle	Adults	22	<1 minute	
Iserson and Criss[78]	13-ga Jamshidi needle	Children, adults	105	≤30 seconds	
Waisman and Waisman[36]	Automatic bone injection device	Adults	50	1–2 minutes	From decision to infusion initiated
Fuchs et al.[84]	15-ga Jamshidi needle	Simulated pediatric model	12	Ranges, 19.1–93.4 seconds	At scene en route to emergency department with turns and stop-and-go driving
				13.8–158.5 seconds	
				13.6–133.1 seconds	
Seigler et al.[49]	15- or 18-ga Jamshidi needle	Children	17	<1 minute	
Seigler[57]	15- or 18-ga Jamshidi needle	Children	69	<1 minute 1–2 minutes 2–3 minutes >3 minutes	57% of patients 26% of patients 10% of patients 7% of patients
Banerjee et al.[73]	18-ga spinal needle with stylet or 16- to 18-ga hypodermic needle with stylet	Children	30	67 ± 7 seconds	Success rate, 33% of IV cannulation within 5 min; successful IV access took 129 ± 13 seconds

ga, gauge

Safety of IO Infusions

Acceptance of the IO route as an alternative means to gain vascular access in emergency situations has been somewhat limited because of lack of knowledge, lack of training, and safety concerns. With regard to adults, these concerns include extravasation of drugs and fluids into soft tissue with development of compartment syndrome, bone fracture at the site of injection, and, particularly, osteomyelitis and fat or bone emboli.

Complication rates reported after IO infusion into both the sternum and the tibia appear to be similar to those reported after IV infusion of the same drug.[35,64] As might be expected, complication rates decreased with familiarity of and experience with the technique.[7] However, the consequences of IO complications, such as osteomyelitis or extravasation of infused drug or fluid into soft tissue, have potentially greater clinical significance than complications after IV infusion. In general, extravasation of fluids and drugs typically has been associated with improper insertions or multiple insertion attempts into the same bone, rather than with the type of IO needle used, and has been implicated in the development of compartment syndrome in children and experimental animals when an extremity site is used.[71,82,90,91] Studies have shown that plasma concentrations of drugs are lower when infused into bone in which multiple IO attempts have been made compared with a single insertion.[55] Therefore, every effort should be made to achieve IO access after a single attempt. An overall evaluation of IO infusions indicates that significant complications are relatively rare,[7,23,57,64,92] although some cases have been reported. This suggests that aseptic technique in the use of IO devices is both practical and effective. In addition, studies in children have reported that osteomyelitis was avoided if the IO needle was removed before 24 hours.[92] Current standard-of-care practice recommends that the IO device should be removed as soon as more conventional IV access can be obtained. It should also be noted that although fat emboli appear to be a common occurrence after IO infusions of fluids and drugs, they do not seem to have clinical consequence,[7,93,94] even when infusions are administered under pressure.[95]

In practice, there are conditions in which IO infusion should be avoided, such as the IO site is on a fractured bone, infusion through dirty skin, or the presence of infection at the injection site.[7,64] In military scenarios, IO infusion through dirty skin may be unavoidable, but the chance of infection can be minimized by replacing the IO needle with an IV line as soon as possible. The presence of bone disease, such as osteoporosis, osteopetrosis, or osteogenesis imperfecta, is considered a contraindication for IO infusion, but it may not be an absolute limitation.[7] Nevertheless, the chance of encountering these diseases in military personnel is almost nil.

A review of IO complications by Fiser,[23] based almost exclusively on pediatric use in the tibia, reported an 80% success rate of insertion and a 20% failure rate attributable to missed landmarks, a bent needle, lack of red marrow, or osteopetrosis. Other failures related to the needle slipping off the bone or the bone being harder than expected.[78] A 0.7% incidence (5 of 694) of localized cellulitis and formation of subcutaneous abscesses was observed. In addition, the incidence of osteomyelitis was observed to be 0.6% (27 of 4,270)[23] and was often associated with continuous infusions for more than 24 hours. In adults, recent use of IO access has been limited, so the success rate and complications await further clinical studies. However, Iserson and Criss[78] reported that radiographic evaluation of IO sites in humans 6 to 16 weeks after insertion revealed no defects or bony distortions.

Extensive histologic examination of the sternum and lungs 2 hours after HSD infusion revealed a similar incidence of minimal lung inflammation whether HSD was infused by the IV or IO route.[44] Focal hemorrhage at the IO site was observed, as was a small 2- to 5-mm region of hypocellularity.[45] None of the reported lesions were rated severe. In addition, extravasation of fluid into the skin above the sternum was not observed. In sheep, no physiologic or histologic evidence of pulmonary embolism was found after IO infusion of HSD.[96] At 1 to 2 days after infusion, hematopoietic cells exhibited a focal washout in the vicinity of the infusion site. Histologic specimens from the infusion site at 2 to 6 weeks after infusion showed replacement of hypocellular areas with fibrous tissue. All of these changes were confined to within a 3-mm radius of the injection site. In the HSD studies, the incidence and severity of lesions around the IO site appeared to be slightly higher in the normal saline group, reflecting the much greater volumes of normal saline required to achieve the same physiologic end points. Pollack et al.[97] also observed no significant adverse effects to tibial bone marrow in swine infused by the IO route with standard emergency resuscitative medications and followed for up to 3 months. It has also been reported that 5% NaCl, administered by the IO route in the proximal tibia of dogs, caused some marrow necrosis and endosteal damage, but the volumes required to induce these effects were not mentioned.[86] Also, neither the osmolality of the fluid nor its rate of infusion was related to histopathologic changes in the bone marrow of swine.[98] From these studies, it would appear that the osteomyelitis associated with IO infusions of hypertonic solutions in the earlier literature does not occur with HSD or the use of newer IO infusion devices or needles.

Training

Available evidence suggests that in addition to good medical care, proper training and practice will minimize most of the complications reported with IO infusions. Thus, training is an important component of the use of intraosseous infusion for obtaining vascular access under emergency conditions. Paramedics, emergency medicine residents, and nurses have used chicken and turkey bones for training and report that the technique is easily learned, even by observation.[49,57,94] These insertions have been successful even when traveling in emergency vehicles.[84] In contrast, data suggest that placing an IV line in a trauma patient in a moving ambulance takes 10 to 12 minutes and has a 10 to 40% failure rate.[6] When the IO needle or device is inserted properly, dislodgement is rare. Although no definitive comparison studies have been performed, proper IO placements are potentially more stable than IV catheters, particularly under transport conditions or in the presence of thrashing motions by the patient.[12] In most studies, a 1-hour lecture, followed by 1 hour of hands-on experience, has been considered sufficient training for paramedics and military first responders.[57,84,99,100] Similar observations were made most recently at the Walter Reed Army Institute of Research (MAJ M. Calkins, unpublished observations). The specialized manikins available to teach pediatric IO access could be modified for training military and civilian first responders. Although the use of local anesthetics before insertion of IO needles is uncommon in children, the need for application of local anesthetics at the insertion site, particularly the sternum, in conscious adults has not received much attention and requires evaluation.[36] It should be emphasized that IO access is an option for obtaining emergency vascular access in a timely manner and that it should not be used to imply that the health care provider is not proficient with IV access. It should also be mentioned that the current alternative for when standard IV access fails is a venous cutdown. This is not a trivial procedure in the hospital setting and is clearly much more difficult and time consuming in the field environment.

Conclusions

Intraosseous infusion has been shown to be a rapid, reliable alternative to achieve vascular access under emergency conditions in children. Based on the available evidence discussed in this review, intraosseous infusion in medical emergencies in adults should be as reliable as it has been in children. In studies with experimental animals, adults, and human cadavers, the intraosseous route through the tibia and the sternum, primarily, has been effective for the delivery of emergency drugs, fluids, and blood. Furthermore, it is possible to cross-match blood and to obtain standard laboratory values through the IO route.[23,89] To date, it appears that any drug or fluid infused intravenously is compatible with IO infusions.[7] In addition, the technique appears to be safe and to have few complications if aseptic conditions can be maintained and prolonged infusion times and multiple insertion attempts into the same bone are avoided. It is recommended that the IO needle be replaced as soon as more conventional IV access can be established. This practice would be similar to present standard-of-care replacement of prehospital IV lines once the patient has reached a definitive treatment facility. However, the majority of recent studies have involved emergencies in children, and much remains to be evaluated in the use of IO infusion routes in adults. Future investigations will need to define the limitations of IO use in adults and preferred infusion sites, particularly in combat situations. Other efforts will be needed to evaluate existing IO infusion needles and more automatic devices and to make necessary improvements. The ideal device or needle should be small, lightweight, reloadable, inexpensive, and easily inserted under any conditions, including blackout, yet be rugged enough to function in the tactical battlefield environment. Again, the IO technique is not advocated as a replacement for conventional IV techniques. Instead, it should be considered as a viable alternative under emergency situations in which gaining vascular access is imperative but conditions (e.g., combat environments) make it extremely difficult for even the most experienced health care provider to obtain IV access.

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